Future Batteries for 12V Automotive SLI+ Applications

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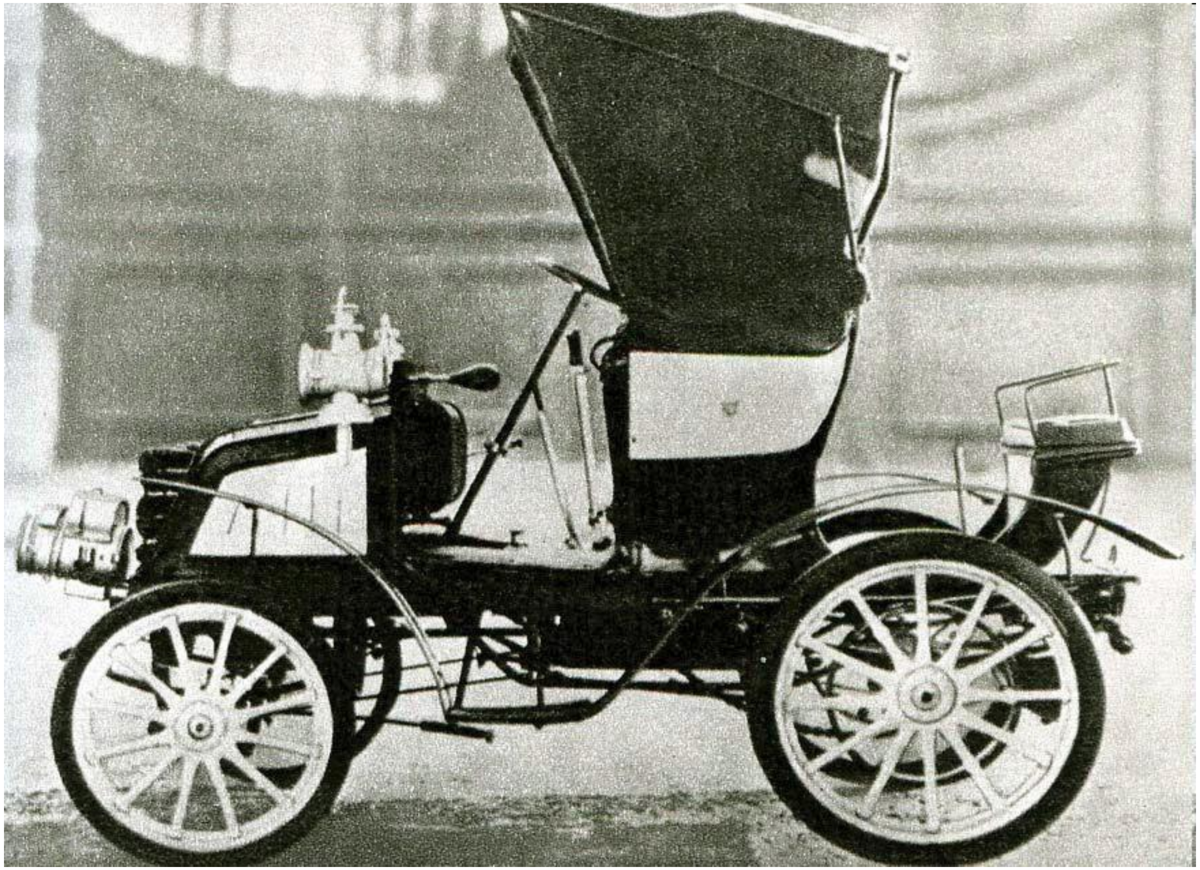
Before Energy Storage on Cars



Engines were manually cranked…

Evolution of Energy Storage on Vehicles – 1

- Until the late 1910s—Manual cranking
- Early-twenties to late 50ies—6V Lead-acid battery for Starting-Lighting-Ignition
- Late 50ies—Transition to 12V systems to support larger engines
- 1960ies to approx. 2000—Focus on:
  - Reducing venting and water-topping needs
  - Cost reduction (in absolute $)
  - Quality enhancement
  - Consolidation of suppliers in the later part of the period

Evolution of Energy Storage on Vehicles – 2

- Since about 2000
  - Use of AGM (sealed) batteries in premium / large cars
  - Increased load on electrical systems
  - Increased need to support idle currents
- Since 2008—Use of passive hybridization and stop/start
- Since 2014—Micro-hybridization and introduction of Lithium ion

Standard Flooded Lead Acid

- **The workhorse of the industry for 100 years**
  - Low cost—commodity—about $40-60 (OEM) for a typical 60-Ah battery
  - Established manufacturing base and logistics
  - Operating-temperature tolerance (engine compartment)
- **Cons**
  - Limited energy throughput (Cycle life)
  - Limited charge acceptance
  - Limited partial SOC operation
  - Not acceptable for cargo/cabin compartment installation
- **Improved designs**
  - They are now available for a moderate cost increase
- **Battery sensor**
  - Improves battery management and life

Modern Vehicle Design—Impact on 12V Batteries

Powertrain—support stop/start and regenerative braking

- Cycling at PSOC (Partial State of Charge)
  - A challenge for lead-acid technology
- Absorb regenerative braking: add extra device or optimize current output of SLI battery?

Power Supply Function

- Added loads require higher output from the battery
- Electrically powered safety features (power steering, power brakes autonomous driving sensors, and cameras) require stable and reliable voltage quality
- Solution
  - Higher-quality lead acid battery
  - Larger lead-acid battery
  - Two batteries (Two lead-acid or 1 Li-ion + 1 lead-acid)
  - Single Li-ion battery

European premium-car makers lead the charge

Design Features: many small changes

1. Plug-less Sealed Lid

   * to condense water evaporated at high temperatures

2. Modified Electrolyte

   * to reduce Lead sulphation

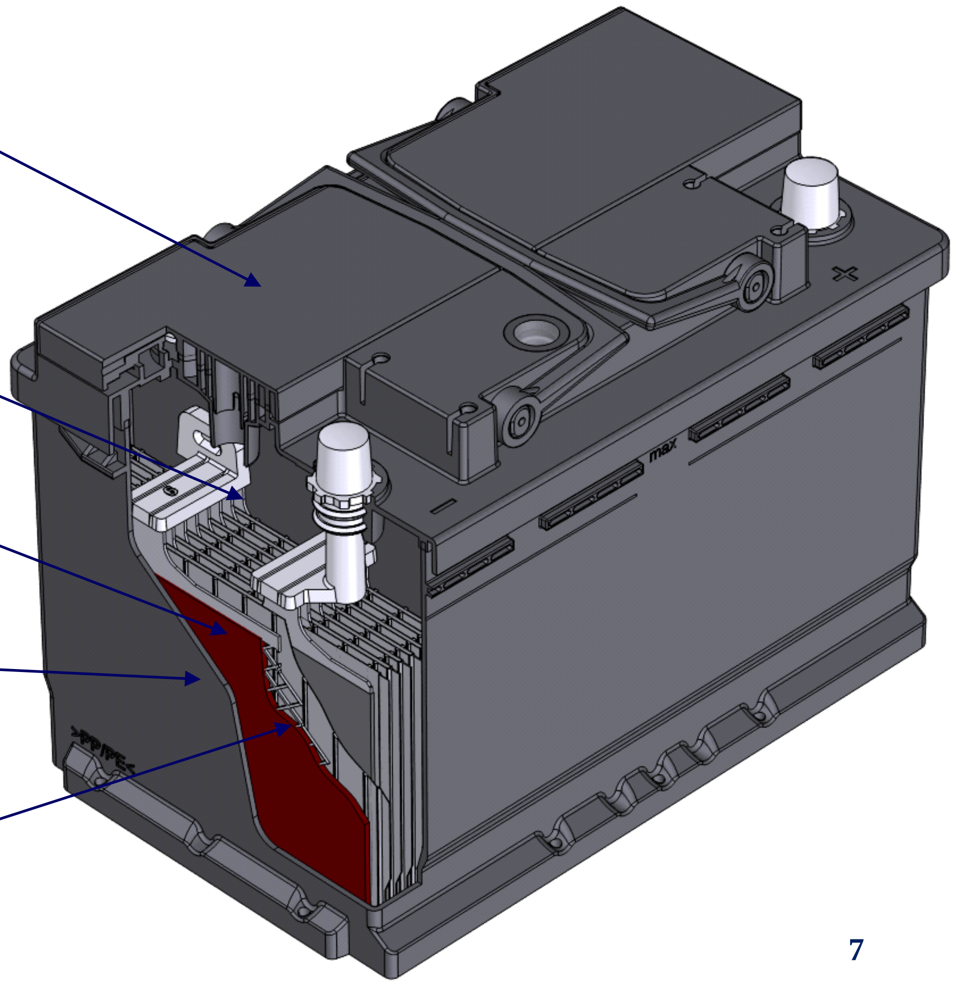
3. Carbon additives

   *For better charge acceptance

4. Nonwoven glassmat)

5. Taller Plates
6. Thicker rolled strips
7. High Sn Low Ca alloy

8. Thick Backweb
9. Polyethylene separator



Valve-Regulated Lead Acid

- Improved cyclability over flooded design
- Current cost almost 1.6X that of flooded batteries
- Charge acceptance and cyclability still much behind those of Li-ion batteries
- Economical (compared with advanced batteries)
- Manufacturing has expanded

- Advanced flooded designs can become standard on most vehicles
- Valve-regulated designs will increase market share at the high end
- Battery sensors will become standard
- Sizes are likely to migrate as requirements evolve
- Advanced designs currently claim higher pricing but…
  - *Carmakers are moving to commoditize the product*

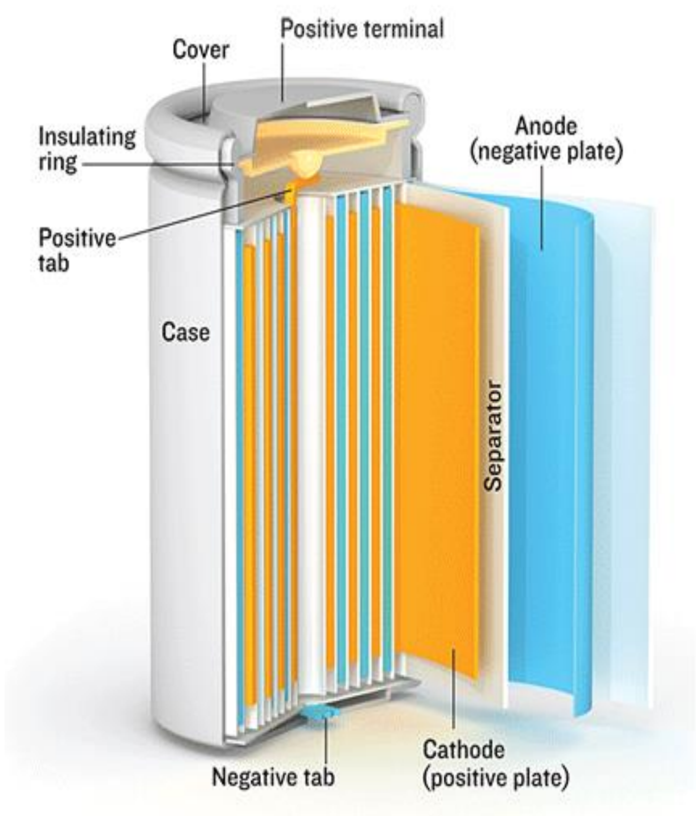
Li-Ion Batteries

- Invented in 1985 at Asahi Kasei, although there are many other contributors
- Commercially introduced in 1991 (Sony)
- Key advantages
  - High energy density
  - Long cycle life
  - Good calendar life
  - High discharge rate
  - High voltage ~3.7 average
  - Low self discharge
  - Extensive R&D effort due to future potential

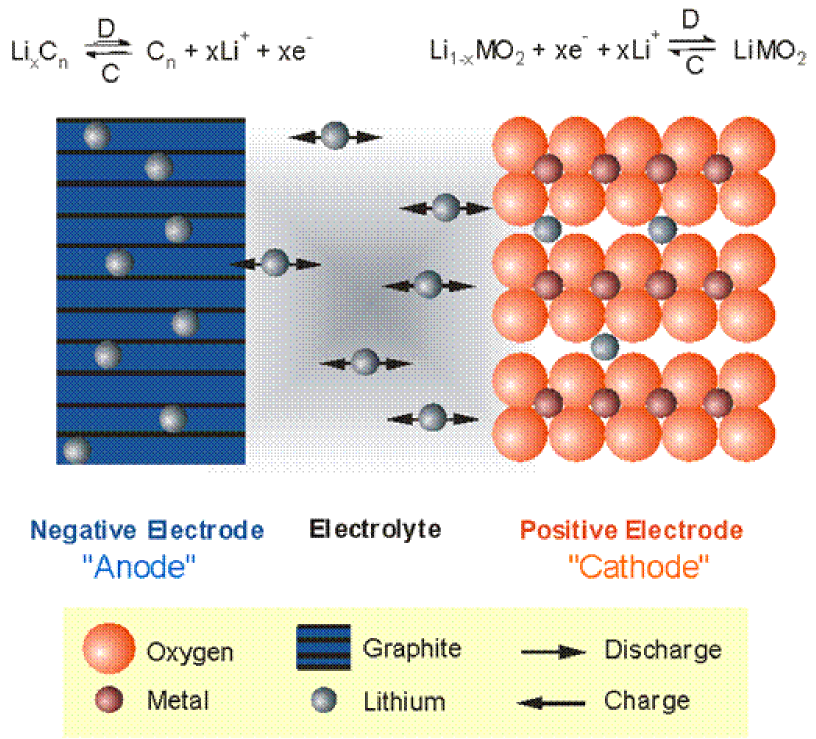
- 1992 – Camcorders
- 1996 – Laptops
- 1998 – Cellphones
- 2003 – Tablets
- 2005 – Space
- 2009 – HEVs
- 2010 -- Robotics
- 2011 – EVs
- 2012 – LEVs
- 2014 – Grid storage
- 20XX – SLI

Downsides are **safety** (flammability of organic electrolyte, overcharge, and internal short circuit) and **cost**.

Conservation of electricity via high-tech chemistry & technology in a can



Internal Chemistry

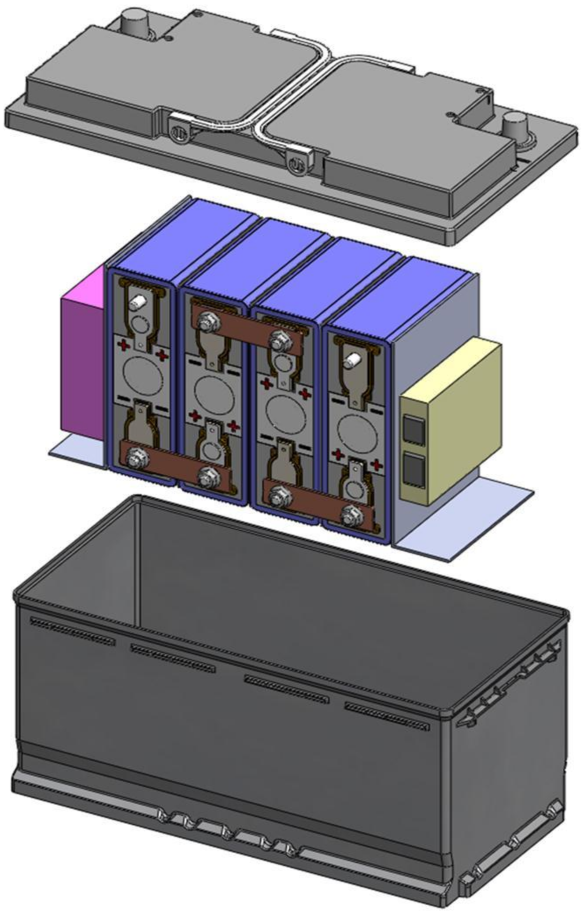


Large Material Variety:

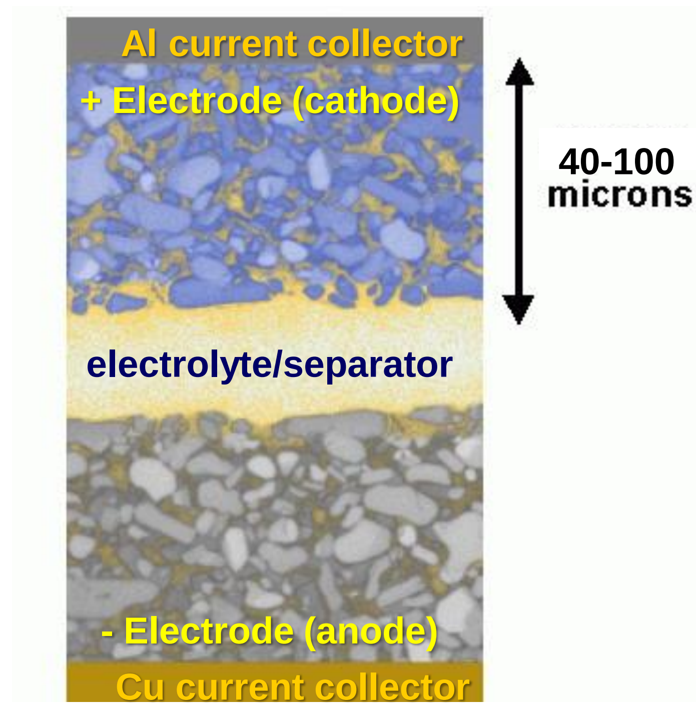
⇒ Evolutionary Technology

Stack Cell and Battery Design

GS Yuasa 13V
SLI Battery



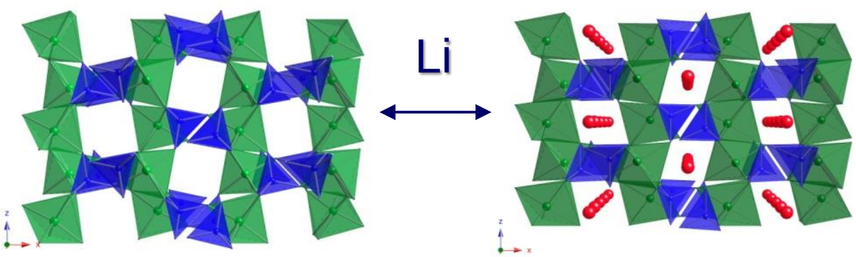
- Regardless of the external shape, Li-Ion cells are internally made of spirally-wound (or stacked) layers of cathode, anode, and separator, as shown on the diagrams below
- Cathode and anode are powder-coated on foil (current collectors are copper for anode, aluminum for cathode)

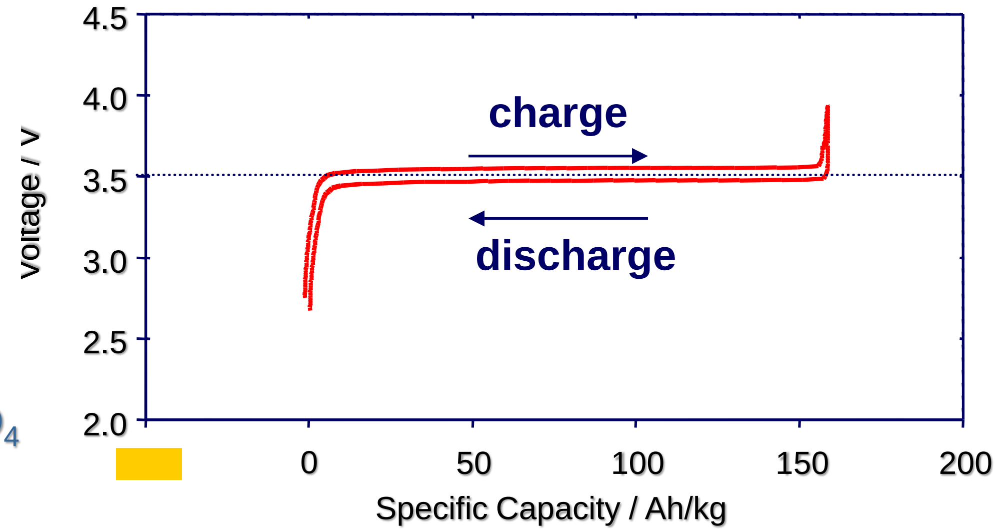


Li Ion for 13V SLI Applications

- Several technologies possible, of which the most attractive for this application is the Graphite/LFP chemistry
- Four 3.3V cells provide a good match for automotive 14V generators and 12V nominal electrical systems
- No rare materials
- No toxicity
- Better abuse tolerance than other Li-ion chemistries

$LiFePO_4$: Back Into the Iron Age?





2-phase Li^+ removal/uptake behavior

$(1\text{-}x)LiFePO_4 + xFePO_4 + xLi^+ + xe^- \leftrightarrow LiFePO_4$

Key Attributes:

- ✓Structural stability ⇒ cycle life, safety
- ✓No significant electrolyte oxidation at ca. 3.5V ⇒ safety, cycle life
- ✓Resistance increase during overcharge ⇒ safety
- ✓Inconsistent life data at higher temperatures ⇒ purity, reliability issue?
- ✓Low raw material cost but difficult synthesis

12V Li-Ion SLI Battery – Pros

CHARGE ACCEPTANCE

- Significantly higher rate of charge acceptance than lead acid
- Maintains charge performance through the life of the battery
- improved fuel economy/emissions

LIFE

Longer life, maybe 2X that of lead acid

WEIGHT

30-50% lighter than lead-acid battery

No Toxic Materials

Lead-free product that is more abuse tolerant than other lithium-ion chemistries

Weight reduction has been the main driver for early 13V Li-Ion adopters

GS Yuasa 60-Ah SLI Cell

Table Specifications of LEV60F Lithium-ion Cells

Cell model			LEV60F
Chemistry			LFP*1 / Graphite
Dimensions	W	/ mm	171
	D	/ mm	55
	H	/ mm	116*2
Volume		/ l	1.1
Mass		/ kg	2.2
Nominal Voltage		/ V	3.3
Nominal capacity		/ Ah	69

*1 LFP: Lithium Iron Phosphate
*2 Without terminal

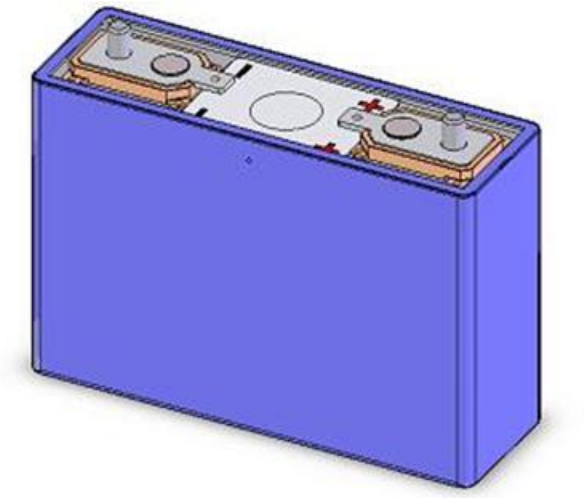


Fig. Appearance of LEV60F cell

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A123 Systems’ Li-Ion 13V SLI+ Battery

	Unit	Performance
Chemistry	-	Graphite / LFP
Nameplate capacity	Ah	60
Nominal Energy	Wh	792
Minimum Voltage	V	8.0
Nominal Voltage	V	13.2
Maximum Voltage	V	14.4
EN cold crank amps (-18°C/-30°C)	A	900/480
Communication / disconnect	-	LIN / relay
Mass	kg	< 12.5
Operating Temperature Range	C	-30 to 65
Recommended Storage Temp	C	-40 to 65
Dimensions (LN3/H6)	mm	278 x 175 x 190

Li Ion Battery – Cons

- Initial price about 3-5X higher
- Less tolerant to high-temperature engine environment
- Power at very low temperatures is still borderline in particular for aged batteries
- Crash safety should be engineered—impact location in vehicle
- Not enough field data for life estimate
- Manufacturing base for an LFP/Graphite SLI battery is limited today
- Recycling is non-existent and challenging

But Li Ion is a fast-moving technology with incredible performance enhancement and cost reduction achieved over the past 25 years

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13V Li-Ion Battery Location in the Vehicle

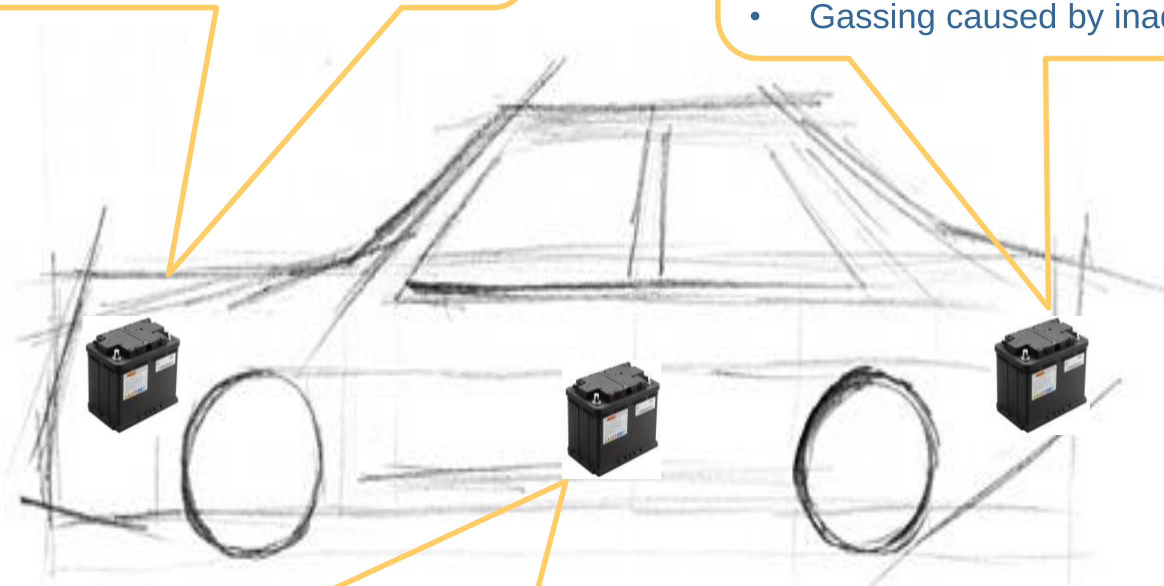
Package Options and their Implications

Under Hood

- High temperature effect on battery life
- Crush-zone implications

Trunk

- Crush-zone implications
- Electrolyte fumes from inadvertent leakage
- Gassing caused by inadvertent overcharge



Passenger Cabin or Open Cargo Area

- Electrolyte fumes from inadvertent leakage
- Gassing caused by inadvertent overcharge

Will the total value of a Li-ion battery exceed cost?

"Drop in replacement" value	Value
Baseline AGM battery cost (80Ah)	€70
AGM warranty	€11 ?
Weight save value (10kg at €5/kg)	€50 ?
Intelligent battery sensor	€9
Sub-total	**€140**

Recuperation value	Value of emission improvement
Penalty avoidance in EU in 2021 (3g CO_2 at 95€/g)	**Up to €285**

For Premium European automakers the total value of a 60Ah, 12V Li-ion battery from 2020 on is up to €425

13V Graphite/LFP Battery Supply

- A 13V, 60Ah SLI battery is about 0.8kWh
  - A Chevy Bolt EV battery is 60kWh
- 1 million Li-ion SLI batteries is equal to about 0.8 GWh
  - 2020 Li-Ion xEV production is estimated at 125 GWh
- 2025 xEV Li-ion batteries are estimated at between 350 and 700 GWh
  - 100 million 13V SLI batteries are equal to only 80 GWh
- Lithium supply is somewhat challenging but expected to be resolved inside the next decade. All other materials are greatly abundant and non-toxic

The manufacturing base for Li-ion SLI batteries should not be a problem

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Summary

- Increased demand for vehicle power has resulted in the development of advanced lead-acid batteries with higher cost.
- Some premium European brands are exploring the use of Li-ion 13V batteries in small-volume high-end vehicles.
- 13V Li-ion batteries provide weight reduction and overall better functionality than the best lead-acid batteries.
- Higher price, 3-5 times the price of current lead-acid products, is the main barrier for Li-Ion implementation in high volumes.
- There are still some other challenges with Li-ion batteries, including operation at very low and very high temperatures, crush protection, and recycling, but they are all technically manageable.
- Battery supply or toxicity should not be an issue.

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For More Information on Li-Ion Batteries for xEVs:

The xEV Industry Insider Report

(October 2017 edition)

An unbiased appraisal of the progress of hybrid and electric vehicles and of advanced automotive battery technology results.

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